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BiSON Birmingham Solar-Oscillations Network

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2014 May 23

(minor editorial revisions 2015 November)

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Abstract

The autoguider was repaired, optics were cleaned, new counters were installed, and a new cœlostat alignment technique suggested. The data are very much improved, but the repairs will not be complete until the primary mirror can be realuminized.

1 Introduction

Steven Hale visited Mount Wilson from 2014 March 31 to April 18. The last visit to Mount Wilson was almost five years previous, in 2009 July [1].

There has been a problem for the last 18 months or so where a strong oscillation at 2.5 mHz and 5.0 mHz has been corrupting the data. The cause of the problems were investigated, some solutions implemented, and additional solutions proposed for future work.

2 The 2.5 mHz Oscillation

The oscillation comes from the tracking errors of the primary mirror. The primary mirror tracks the Sun throughout the day. It has 432 teeth, and it rotates at half the solar rate. That is to say, it makes one full revolution once every 48 hours. From that, we can work out what frequency we expect it to put into the data as a tracking error due to the worm "stepping over" each tooth on the gear as it rotates. This is not a mechanical fault, it is just an inevitable effect of a gear drive-train.

The expected frequency would be:

432 teeth / 48 hours = 9 teeth per hour.

9 per hour / 60 minutes / 60 seconds = 0.0025 Hz = 2.5 mHz

That is precisely 2.5 mHz, with possible harmonics at 5.0 mHz and higher. The autoguider makes tiny adjustments to the alignment of the secondary mirror to compensate for these tracking errors, and any other errors such as those introduced by atmospheric effects. The first-flat "tracks" the apparent motion of the Sun as the Earth rotates, whilst the second-flat performs fine "guiding".

The performance of the autoguider has been poor for some time now. It has not been sufficiently removing the tracking errors, and these errors have become the dominant signal in the data. The causes of this poor performance, and the work required to solve it, are discussed in the following sections.

3 Guider Repairs

3.1 Second-flat Drive Motors

The cables to the two motors and tachometers are very old. The insulation on most of the wires has decayed and long since disappeared, leaving only the bare corroded conductors. This meant that the speed-sensing signals from the tachometers to the guider control system were not reliable, leading to very poor guider performance.

The two cables, labelled SP120 and SP65, were replaced from the mirror down to the junction box below the mirror. A third cable, labelled SP63, was not replaced due to time constraints. This cable handles the limit switches and could not be changed without disassembling both the motor assemblies in order to gain access to the micro-switches. It is recommended that it also be replaced as soon as possible.

The cables in the tower shaft all the way to the control room were not replaced. Hopefully these cables will still be in good condition since they have not been exposed to UV or adverse weather conditions. Additionally, it was not possible to determine where either SP120, SP65, or SP63 terminated in the control room. The labels on the back of the electronics rack were not able to be identified.

In order to replace SP120 and SP65, the connectivity had to first be determined since no schematics were available. Each cable actually consists of two cables in one connector, with one cable going to each drive axis.

The motors consist of a combined motor and tachometer. Both the motor and the tachometer each have a six-way screw terminal block mounted on them, with each terminal labelled 1 through 6. Tables 1 and 2 show which of the two cables are connected to each terminal on the block.

3.2 SP120

The SP120 cable was replaced with two lengths of two-core shielded 16/0.2 (20 AWG stranded "heavy duty") cable. This is thicker than the original cable and so hopefully it will be more resistant to breakage when the mirror is rotated back-and-forth each day.

The 20-way connector is made by "EDAC" and is RS 259-9568. The solder tags used with the connector are RS 476-485. The rear housing and strain-relief were re-used from the original cable. The connector has two guide pins that can be arranged to provide 288 different mating combinations. The default polarizing code is PG1G1. The two guide pins had to be unscrewed and rotated to configuration PG6G6 in order to mate with the panel. This needs to be done using a special flat-blade screwdriver with a notch cut in the middle to step over the end of the guide pin itself.

The pin-out of the cables are shown in tables 3 and 4.

Tachometer 6-way Connector Block	Cable Type
1	SP65
2	SP65
3	SP65
4	SP65
5	NC
6	SP65

Table 1: Each tachometer has a six-way connector block attached to it. The cable type attached to each pin is shown.

Motor 6-way Connector Block	Cable Type
1	SP65
2	SP120
3	SP65
4	SP120
5	NC
6	NC

Table 2: Each motor has a six-way connector block attached to it. The cable type attached to each pin is shown.

SP120 EDAC 20-way	Tach	Motor	Colour
A		2	Red
B		4	Blue
C		NC	Shield/White

Table 3: SP120 East/West cable

SP120 EDAC 20-way	Tach	Motor	Colour
D		2	Red
E		4	Blue
F		NC	Shield/White

Table 4: SP120 North/South cable

3.3 SP65

The SP65 cable was replaced with two lengths of six-core shielded 16/0.2 (20 AWG stranded "heavy duty") cable. This is thicker than the original cable and so hopefully it will be more resistant to breakage when the mirror is rotated back-and-forth each day.

The 17-way connector is a MIL, but it is threaded rather than the bayonet type. It looks like it may be RS 298-2443. Luckily, we were able to acquire a replacement from the 150-ft Tower rather than having to purchase one.

The pin-out of the cables are shown in tables 5 and 6.

SP65 MIL 17-way	Tach	Motor	Colour
A	3	3	Black
B		1	Red
C	2		Yellow
D	6		Green
E	4		Blue
L	1		White

Table 5: SP65 East/West cable

SP65 MIL 17-way	Tach	Motor	Colour
F	3	3	Black
G		1	Red
H	2		Yellow
J	6		Green
K	4		Blue
M	1		White

Table 6: SP65 North/South cable

3.4 Tilt Cams

The second-flat uses two linear cams to control the tilt of the mirror. The lower cam-roller on the east/west axis was badly aligned. It was tilted at an angle to the cam and so this would have been preventing the east/west axis from moving freely. The roller was adjusted to correct alignment by loosening the two screws at the bottom of the roller mount and re-tightening with the roller in the appropriate position.

All the cam-rollers feel quite stiff. They should probably be replaced to allow for a more smooth guiding motion. It would be good to be able to remove the second-flat and take it to a workshop where it could be completely disassembled and refurbished.

3.5 Guider Head Noise

When power is first provided to the guider head, a loud grinding noise is heard. This gradually reduces, and eventually goes away completely after half an hour or so. The cause of the problem was not investigated. It could be the motor, or a bearing, or even the spinning mask itself. This should be checked with some urgency.

At the 150-ft Tower, they leave the guider head powered permanently and it does not make any noise. This can only be done because there is someone permanently available to shut the system down in the event of an electrical storm. Unfortunately, this is not the case at the 60-ft Tower and so everything has to be shut down as soon as the tower is unattended.

3.6 Primary Mirror Damage

On 2013 May 30 the primary mirror was damaged. Normally a mark on the mirror would simply result in a reduction in light intensity, but for us the problem is catastrophic. Our spectrometers are configured to image light from the Sun into the potassium cell. However, at Mount Wilson the spectrometer does not point directly at the Sun. The light comes via the cœlostat that is 60 ft away at the top of the tower. For us, 60 ft away is basically infinity. An image of the surface of the first-flat is formed in the cell. Any marks on the surface of the mirror will be in sharp focus and causing uneven weighting of the solar disc.

With a typical cœlostat even this wouldn't cause too many problems. Usually a cœlostat will both track and guide the first-flat, and the second-flat will be fixed in position. This means any marks on the surface are completely stationary within the image. But the Mount Wilson cœlostat is a little unusual. It tracks on the first-flat and guides using the second-flat. This makes it absolutely essential that the first-flat is spotless and in perfect condition, since any marks will move with respect to the image of the Sun as the guider compensates for tracking errors, and thus periodically change the weighting of parts of the solar disc. This gives rise to a signal that is seen to oscillate at the rate of the tracking error. The damage to the first-flat makes the spectrometer very sensitive to any tracking errors. The mirror needs to be realuminized as soon as possible.

3.7 First-flat Position Adjustment

The two mirrors in the tower shaft pick-off only a small section of the beam from the cœlostat and feed it into our spectrometer. It is unfortunate that the damaged area of the first-flat is close to our pick-off mirrors, and therefore is within the light seen by the spectrometer.

Once the cœlostat is aligned and track and guide are engaged, it is possible to make position adjustments to the first-flat (east/west and north/south in Declination) and "select" different areas of the mirror so that the damaged area can be moved away from the section that is picked-off. It was hoped that by doing this the damaged area could be avoided.

Unfortunately, whilst it was certainly possible to "move" the damaged area so that it no longer appeared in the image projected from the finder-scope next to the spectrometer, it then caused other problems. If the first-flat is moved too far away from optimal alignment in Declination, then this reduces the performance of the autoguider. If the first-flat is translated too far east/west then the beam can clip the edge of the second-flat and cause vignetting. Both problems are unacceptable, and so any further experimentation with mirror positioning was abandoned. It is recommended that only the "correct" position and alignment, discussed later, should be used.

3.8 Summary

There are two faults causing the 2.5 mHz tracking errors to dominate the signal. These are the old damaged motor cabling causing poor guiding quality, and the damaged mirror causing high instrumental tracking error sensitivity. Either fault on its own reduces the data quality, but both faults combined totally destroys the data.

Looking through the operations log for 2013 we can see the time-line of events.

2013 March 11
: The data are noisy. Looks like a guider oscillation. It's probably a broken cable.

2013 May 30
: The primary mirror has been damaged.

2013 June 4
: The guider oscillations are getting worse.

2013 September 14
: The data still have a strong oscillation.

2013 September 17
: The data today look very good.

2013 October 15
: The oscillation is very strong again.

The symptoms began in 2013 March and were due to the poor quality cabling of the guider motors and tachometers. Immediately after the primary mirror was damaged in 2013 May we noticed that the fault was considerably worse. The variation in quality throughout the rest of 2013 is due to the intermittent nature of the cable fault. Since the cables are moved as the second-flat is rotated from the morning to afternoon configuration and back again, it follows that they can be connected and conducting in one direction, but then disconnect when flexed in a different direction. The signal quality can vary day to day.

The guider performance is also affected by how well the first-flat is aligned with the second-flat at the start of each observational run. The poorer the alignment (for example the further out the first-flat is in Declination) the harder the guider has to work. It is important that care is taken to get the alignment as close as possible before starting observing.

We can summarise this into three phases.

2013 March
: Good mirror, bad cables. With a good mirror the spectrometer has low sensitivity to tracking errors. The bad cables give poor guider performance, but the symptoms are relatively minor to begin with.

2013 May
: Bad mirror, bad cables. The mirror gets damaged which makes the spectrometer very sensitive to tracking errors. Combined with poor guider performance, we have data that are destroyed by tracking errors.

2014 April

> Bad mirror, good cables. The autoguider is fixed. We now have very good guiding with very low tracking error. But we still have high tracking error sensitivity. The guider is performing as it should and doing its best, but the spectrometer is just too sensitive. This means the error still shows through, but no where near as badly as it did before we fixed the autoguider.

Repairing the guider has vastly improved the quality of the data. But the only way to fix the problem completely is for the primary mirror to be realuminized and enter phase four — good mirror, good cables.

4 Cleaning

The mirrors were cleaned using a method recommended by John Boyden.

This technique involved spraying each mirror with a mixture of distilled water and sodium laurel sulfate — basically soapy water. As the soapy water runs off the surface of the mirror, it takes with it most of the dust and dirt. A wet-capable vacuum cleaner was used to suck up the dirty water as it ran off, in order to prevent anything else from getting wet.

The mirror would then be coated again with soapy water and the surface gently rubbed with finger-tips to remove any more stubborn particles, being careful not to rub too hard and damage the surface.

Finally, clean distilled water is used to rinse the mirror, and the vacuum cleaner used to dry the surface by sucking away the water before it has time to dry and leave a water mark.

Four of the five mirrors were cleaned on this visit. The second-flat was not cleaned, since it faces downwards it does not get very dirty and already looked clean. In addition, the beam splitter used to send light to the guider head was cleaned, and also the front red filter of the spectrometer.

The two pick-off mirrors in the tower shaft, and the final mirror just in front of the spectrometer, all have some paint spots from when the tower was painted back in 2011. These were unable to be removed. They are also unable to be realuminized since they are glued onto their wooden mounts and so the only way to recover this damage will be to buy new mirrors.

When re-installing the pick-off mirrors, an improvement was made to the alignment so that the finder-scope at the bottom of the tower now projects an image of the entire solar disc. For many years the right-hand side has been vignetted since the alignment was not quite right. It is actually very difficult to align the mirrors, since the clamps on the optical bench that holds the mounts move as you tighten them. You have to offset the component, and then hope that it pulls back into the correct place as you tighten the mount. This means it takes a lot of trial-and-error and stubborn persistence to obtain the best alignment.

After the cleaning was completed, the intensity measured by the spectrometer almost doubled. Hopefully this improvement will mitigate the effect of the damaged part of the first-flat.

5 Counters

The old counter modules were replaced with our new "Tiger" counters. These have already been deployed at three other sites, and as expected the installation was straightforward.

As at our other sites, the signal from these counters is significantly cleaner than the old counters, and a good improvement in noise level — particularly at high frequency — was seen.

6 Tuning

6.1 Guider Head Alignment

The guider-head can move on an X/Y mount. The left/right motion corresponds to translating the beam east/west. The up/down motion corresponds to a north/south translation since the light is going through a 45 degree beam-splitter. The guider keeps the beam at a constant position in terms of angle, but this adjustment allows the beam to be moved in terms of absolute position inside the tower shaft.

By looking down the tower from the top of the shaft, it is possible to see where the beam of light is falling at the bottom. The beam is currently not correctly centered on the objective lens, figure 1. It is biased to the south-east. The bias to the south is good because it means our pick-off mirrors are closer to the center of the beam. The bias to the east is not good, and the beam needs to be moved west to become more central. However, this can not be done because it would put the damaged part of the mirror directly over the area picked off by our mirrors.

In any case, it appears our pick-off mirrors are well illuminated. The beam would have to drift a long way for our spectrometer to experience vignetting. No adjustment to the guider-head position was made. This could be revisited once the first-flat has been repaired, and some improvement then made to the beam position.

6.2 Mirror Alignment Scans

A basic alignment was performed by removing the interference filter so that the beam was visible through the spectrometer. The fifth-mirror was then adjusted to center the beam all the way through the instrument. This alignment suggested that the x-micrometer should be set at 9.10 mm and the y-micrometer at 5.85 mm.

Later, a more quantitative alignment was performed by scanning the fifth-mirror in 0.25 mm increments and plotting the resulting data. These plots are shown in figures 2, 3, 4, and 5. These plots suggest that the basic alignment was almost perfect, with only a small change required on the x-micrometer.

The final settings were confirmed as 9.15 mm on the x-micrometer, and 5.85 mm on the y-micrometer. It is suggested that the basic visual alignment is sufficient for future trips.

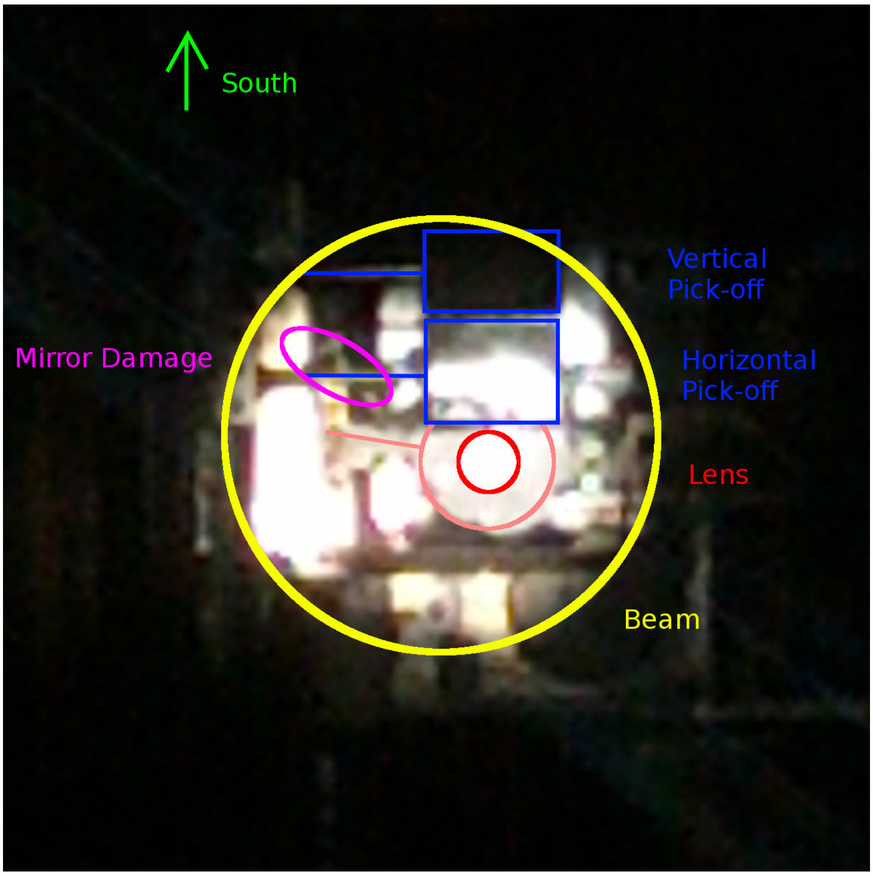

Figure 1: Beam position, looking down the tower shaft.

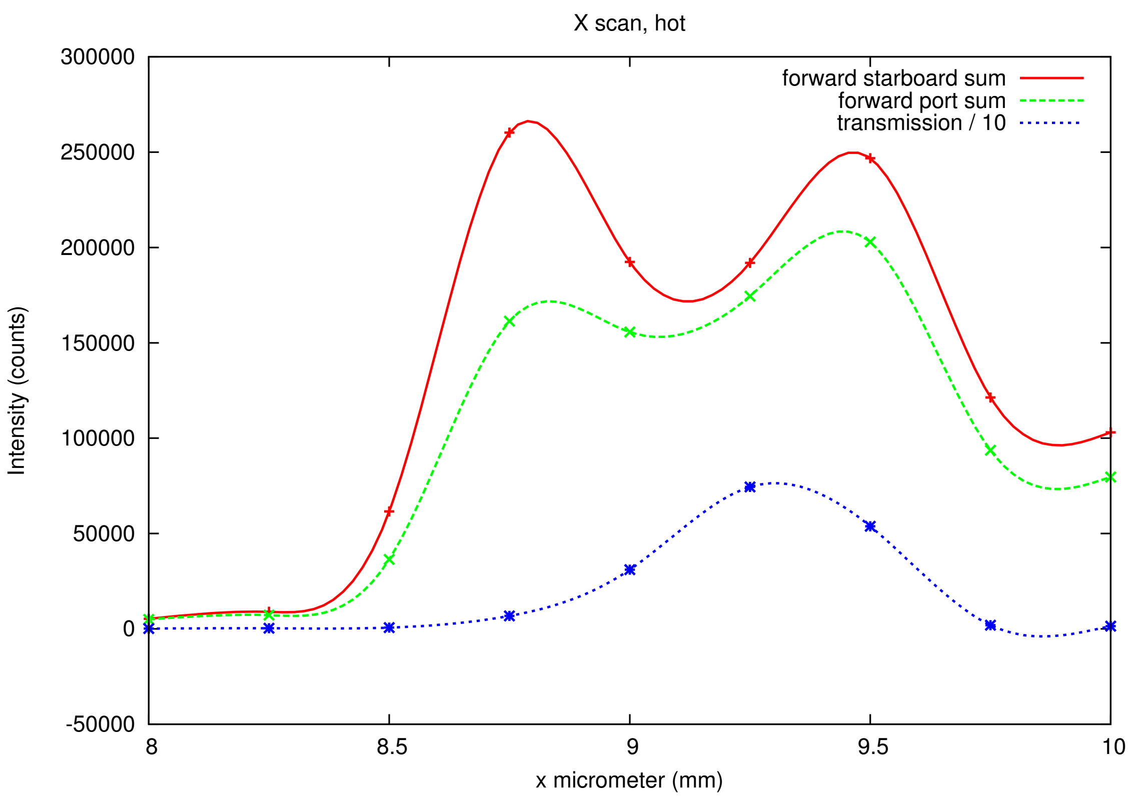

Figure 2: X Hot Sum

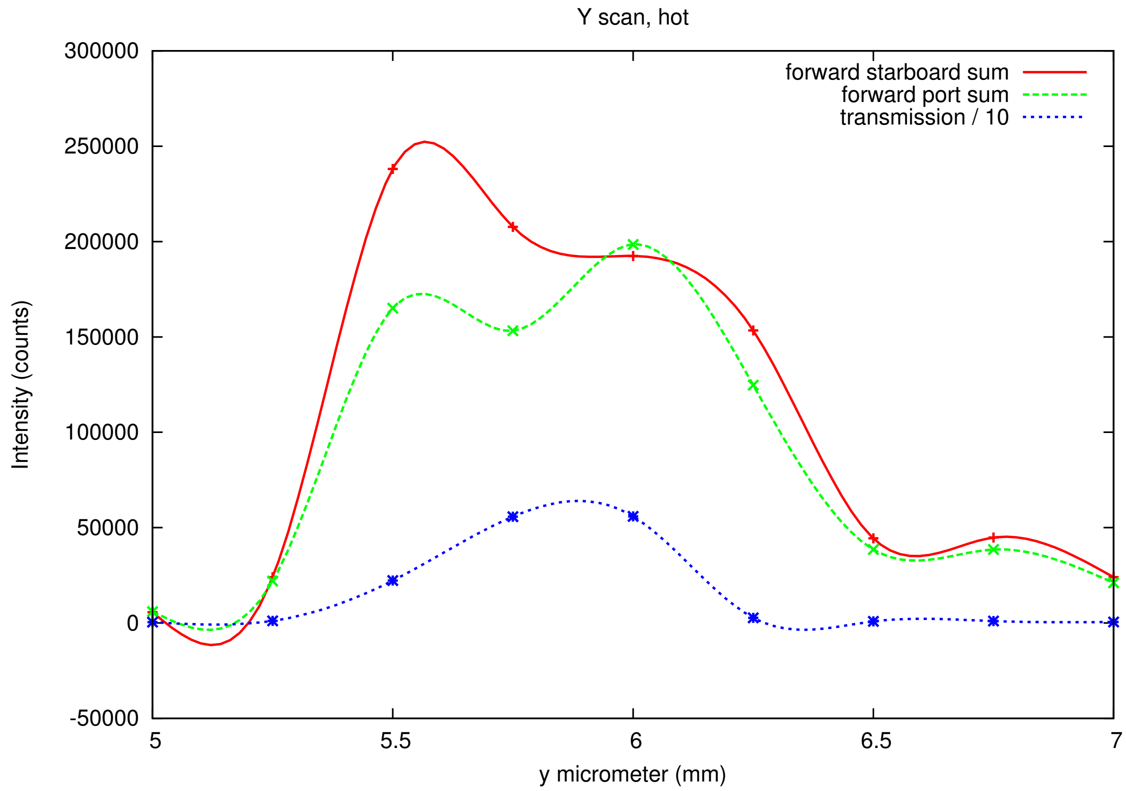

Figure 3: Y Hot Sum

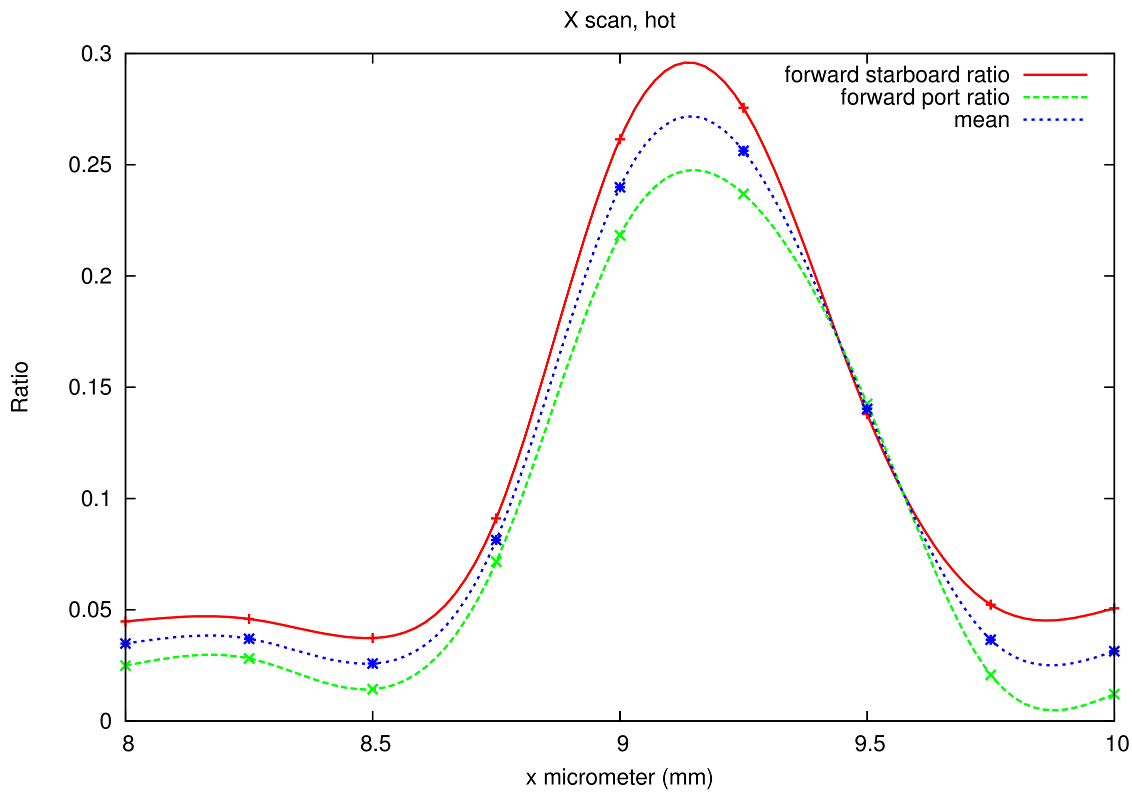

Figure 4: X Hot Ratio

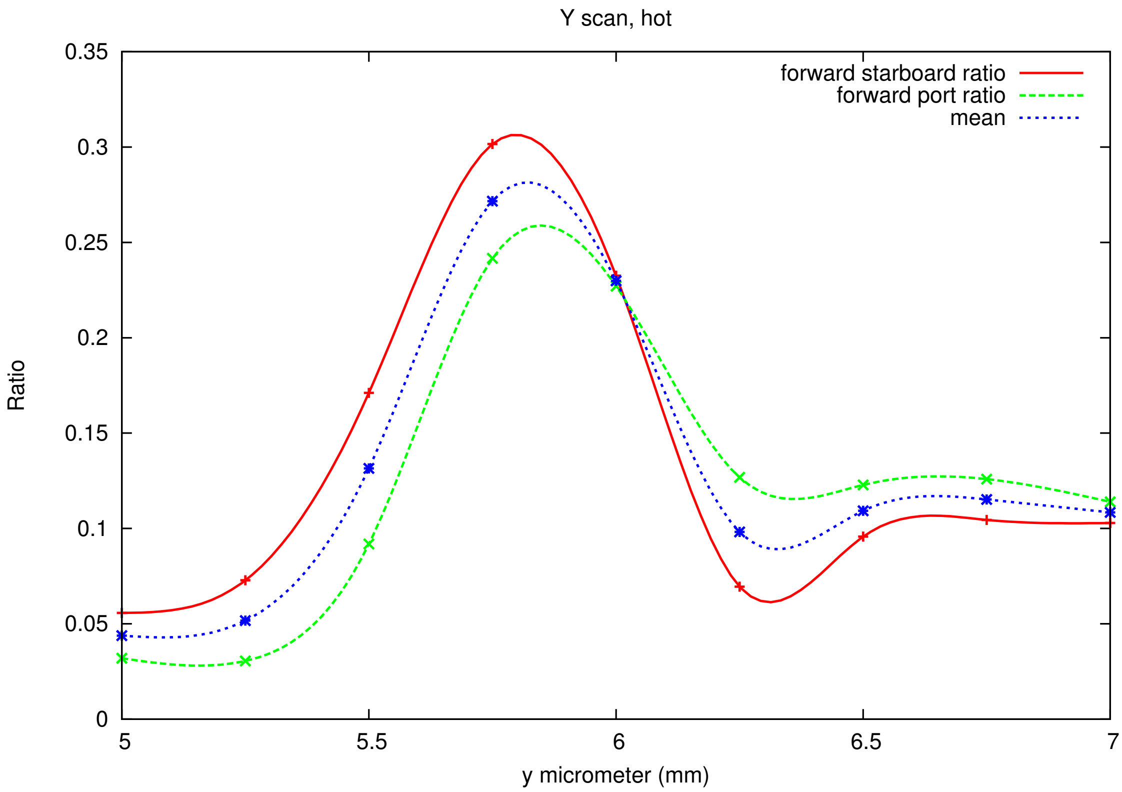

Figure 5: Y Hot Ratio

6.3 Pockels' Cell Driver Power

Mount Wilson uses one of our old-style Pockels' cell drivers. These are basically big amplifiers, and so the output voltage is proportional to the square-wave phase-switching signal. This means that since the counters have been replaced, and a new phase controller is being used, it is likely that the PCD needs to be re-calibrated. Our newer digital PCD do not have this problem and so this additional calibration step would not be required.

The initial dial setting was 330 units on the front of the PCD. This was swept in increments of 10 units and the ratio plotted against these values. The result is shown in figure 6.

There was unfortunately some brief intermittent cloud during this test, which explains the slight drop-out for the 310 unit value. Nevertheless, it is clear that the optimum ratio is found at the slightly reduced power setting of 300 units.

The final setting was confirmed as 300 units on the dial.

6.4 Cœlostat Alignment Technique

It is quite tricky to align the cœlostat mirrors, especially in the morning when the angles involved are larger and the image distortions greater. In the past, an aperture was placed over the first-flat to produce a very narrow beam, and a set of rubber bands used on the second-flat to form a cross-hair. Using this method it was very easy to get the light from the first-flat exactly centered on the second-flat. This is extremely important since if the alignment is off, particularly in Declination, the harder the guider has to work and the greater the likelihood of seeing tracking errors in the data.

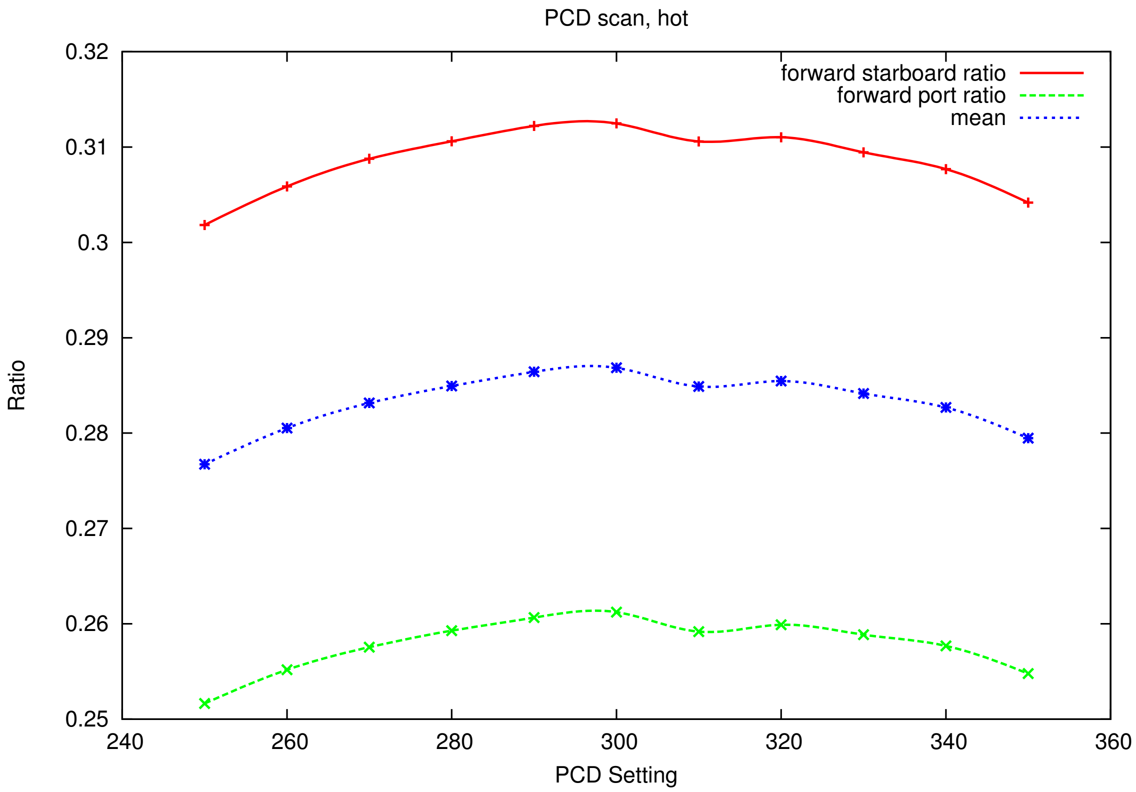

Figure 6: Pockels' Cell Driver Power Setting

Unfortunately this method had been lost to time, as observers have come and gone. Luckily the old cardboard shadow-mask was found, but it was in very bad condition. A new one was fabricated from some new cardboard using the old mask as a template. A bag of rubber bands was purchased from a local store.

The technique was attempted using the new shadow-mask, and it works well. It is easily possible to achieve accurate, consistent, and repeatable alignment. It is recommended that the shadow-mask and rubber bands are used to align the mirror at the start of every observation run from now on.

7 Recommendations

The primary mirror desperately needs to be realuminized. The damage to the mirror causes the spectrometer to be very sensitive to tracking errors, and this needs to be repaired with urgency. Hopefully, it will be possible to include the mirror with one of the future CHARA realuminization runs.

The guider head noise when the system is first powered should be investigated, and the motor or spinning mask replaced if found to be the source of the noise.

The limit switch cables and micro-switches should be replaced, and tested to ensure the system responds correctly when all limits are reached.

References

[1] Steven J. Hale. Temperature controller repairs in Mount Wilson in 2009 July. *BiSON Technical Report Series,* Number 329, High-Resolution Optical-Spectroscopy Group, University of Birmingham, UK, September 2009.